Review of SRF Cavities for ILC, XFEL, and ERL Applications

H. Hayano, KEK

Outline

In a view point of cavity performance related to beam dynamics.

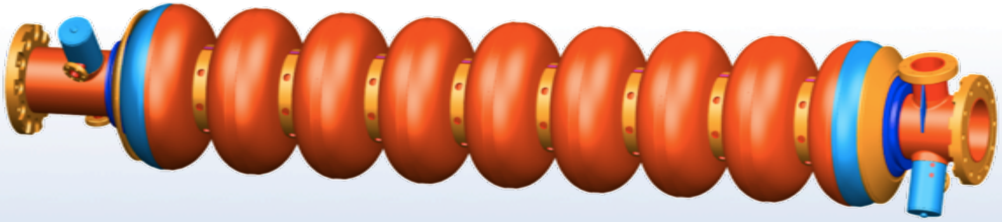
1. Superconducting multi-cell cavities

Fabrication, Tuning, Surface treatment, Testing
Gradient performance

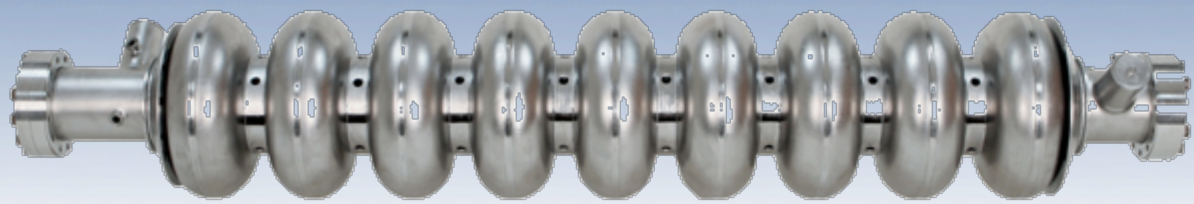
2. Technology for High Quality Beam

HOM damper, Piezo tuner, Digital feedback control
Coupler kick issue
Alignment tolerance for long ILC linac
HOM-BPM for alignment confirmation

Superconducting Multi-cell Cavity

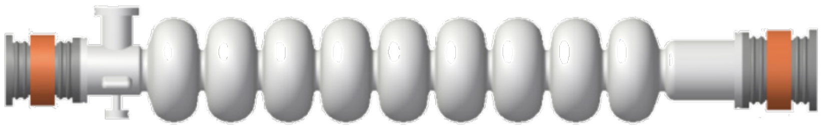


Superconducting Multicell Cavities

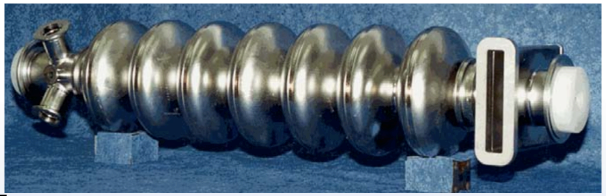


1.3GHz TESLA cavity for XFEL, project-X and ILC

variations
- Frequency
- Cell shape
- HOM damping scheme
- Input coupler

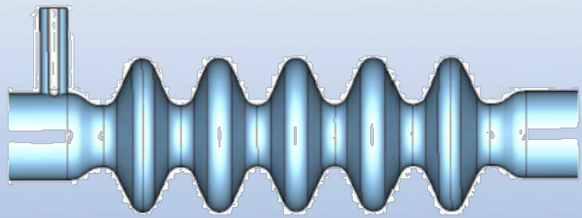


KEK ERL 9-cell cavity (1.3GHz) with beam pipe HOM absorber.

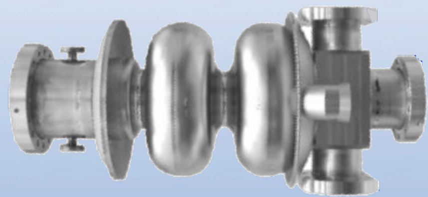


JLAB 12GeV upgrade
7-cell cavity of 1.5GHz
with HOM coupler

JLAB 100mA cryomodule
5-cell cavity of 1.5GHz
with waveguide HOM coupler



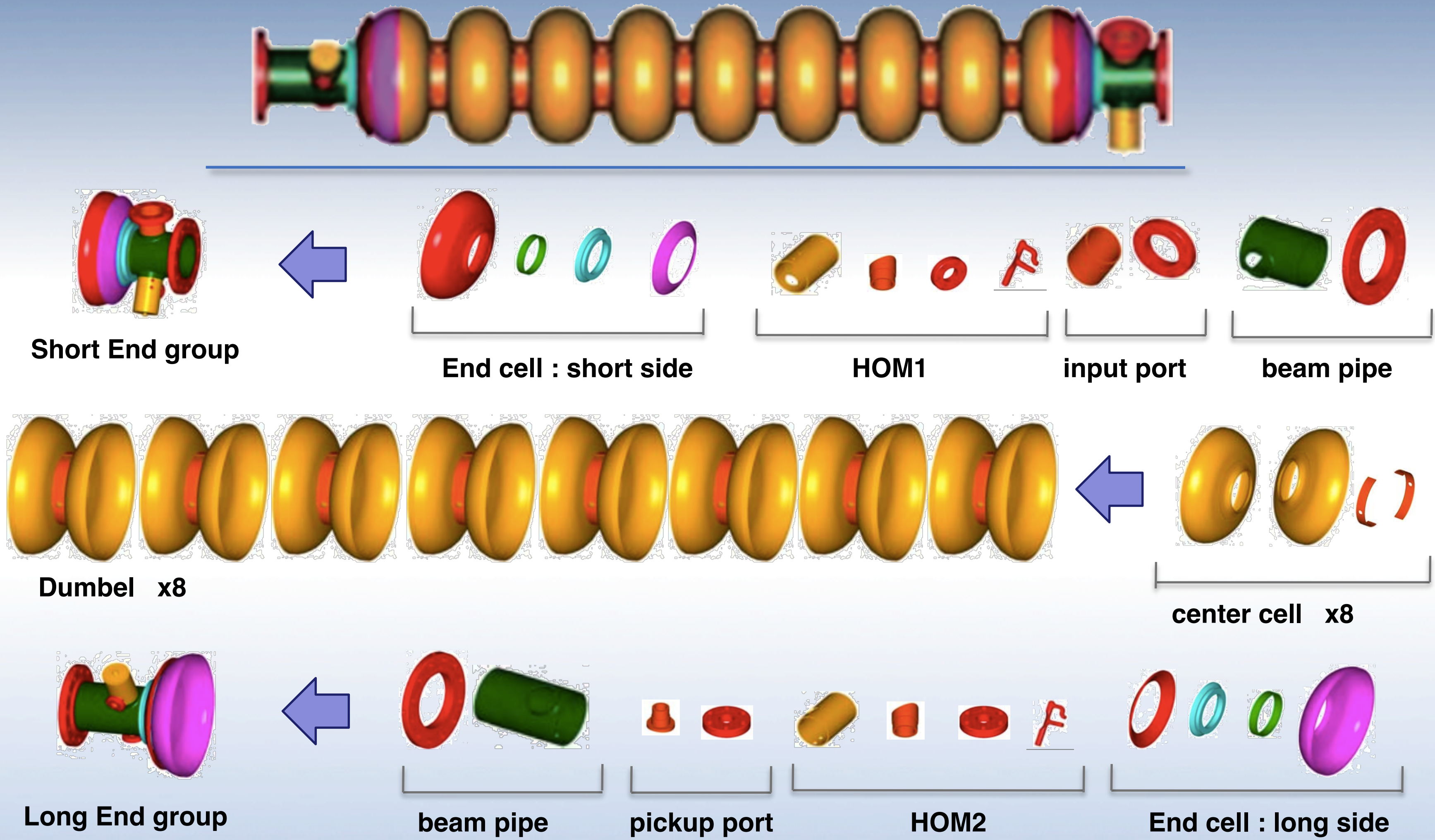
BNL ERL 5-cell 703MHz cavity



Cornell 2 cell cavity
for ERL Injector

KEK 2 cell cavity
for ERL Injector

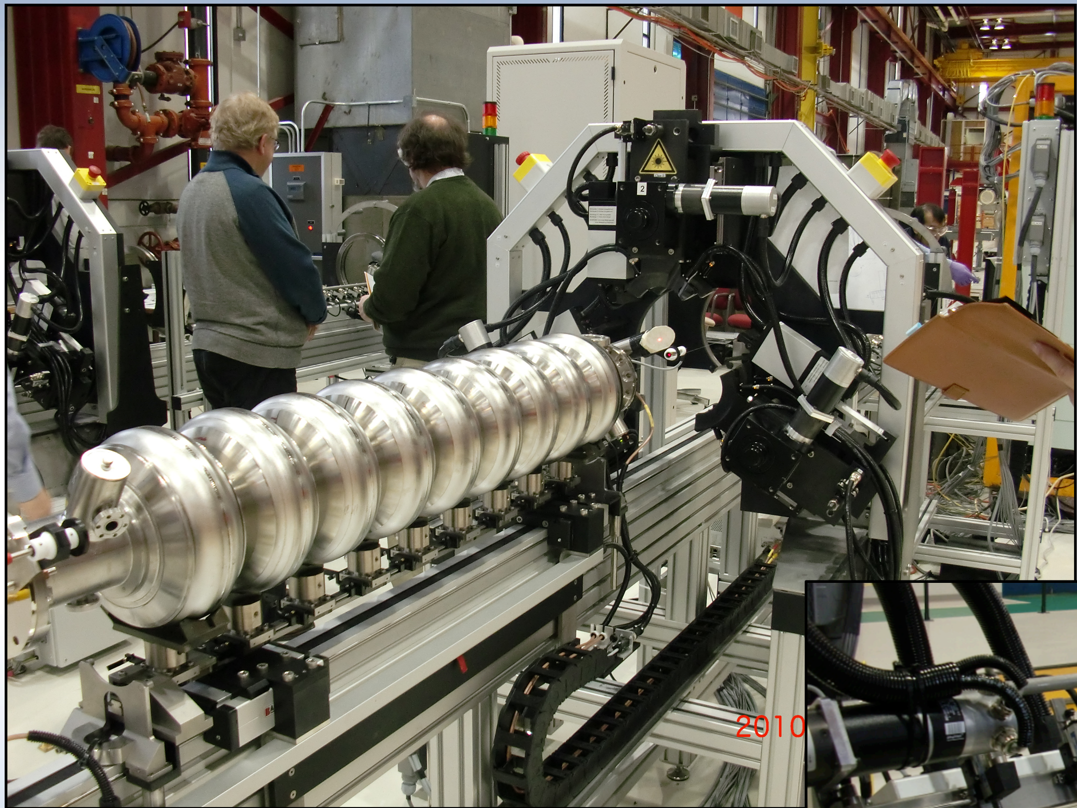
TESLA Cavity Fabrication



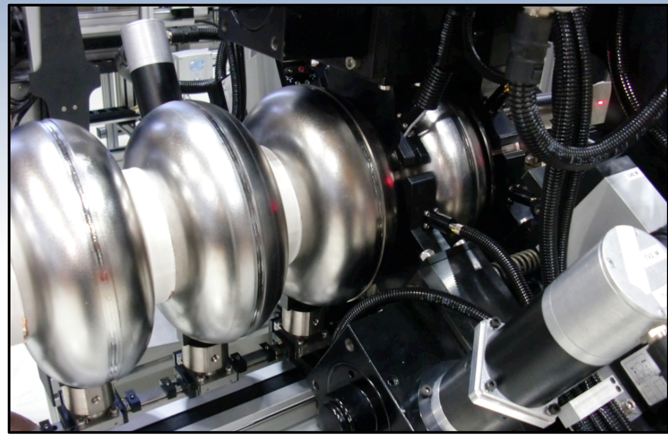
56 parts: Nb (RRR>300)= 46, Nb-Ti = 10, by press, burring, machining
75 Electron Beam Welding (EBW) place

Cavity Frequency & Straightness Tuning

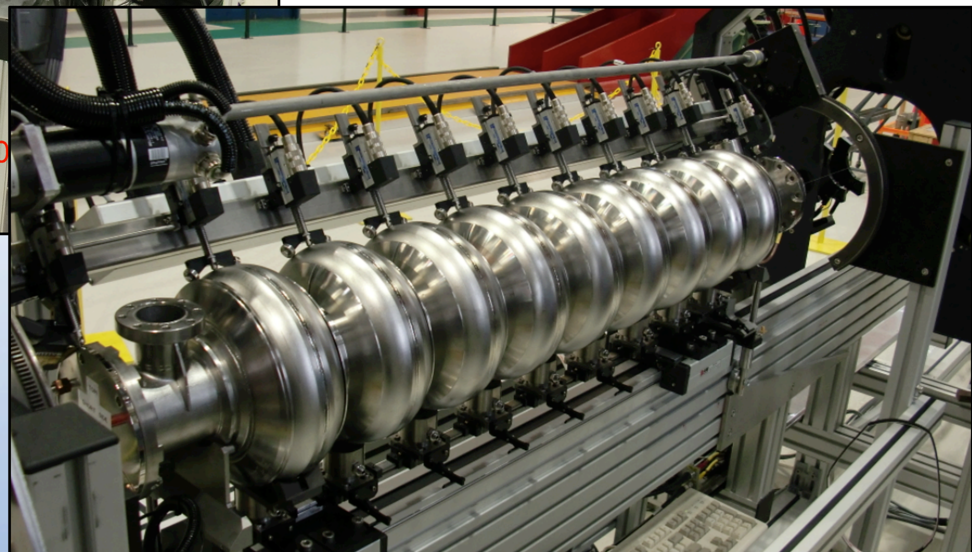
π-mode frequency, field flatnes and eccentricity tuning done by 6 jaws.



DESY-FNAL-KEK Pre-tuning machine

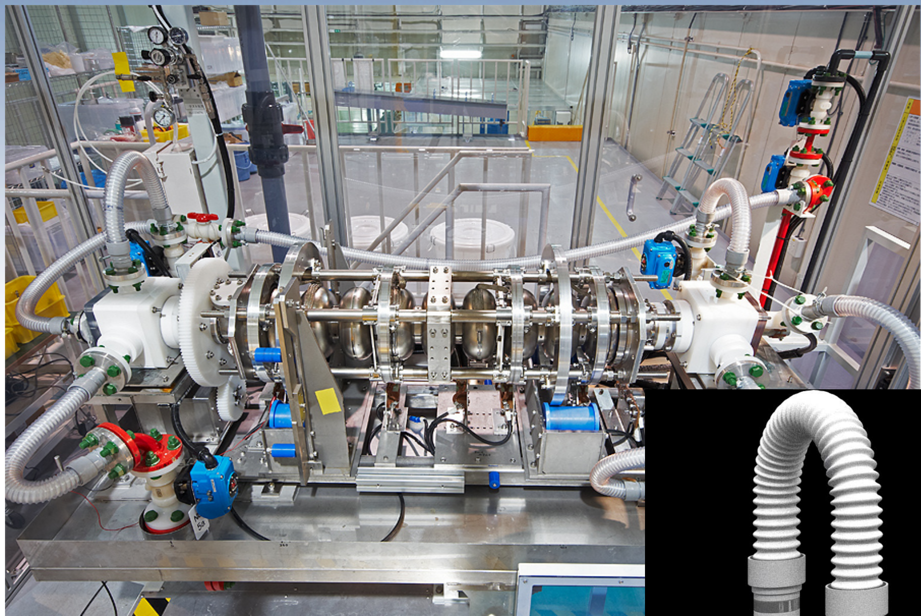


Push and Pull freq. tuning by 6 jaws,
keeping cavity straightness.



Each cell eccentricity measurement

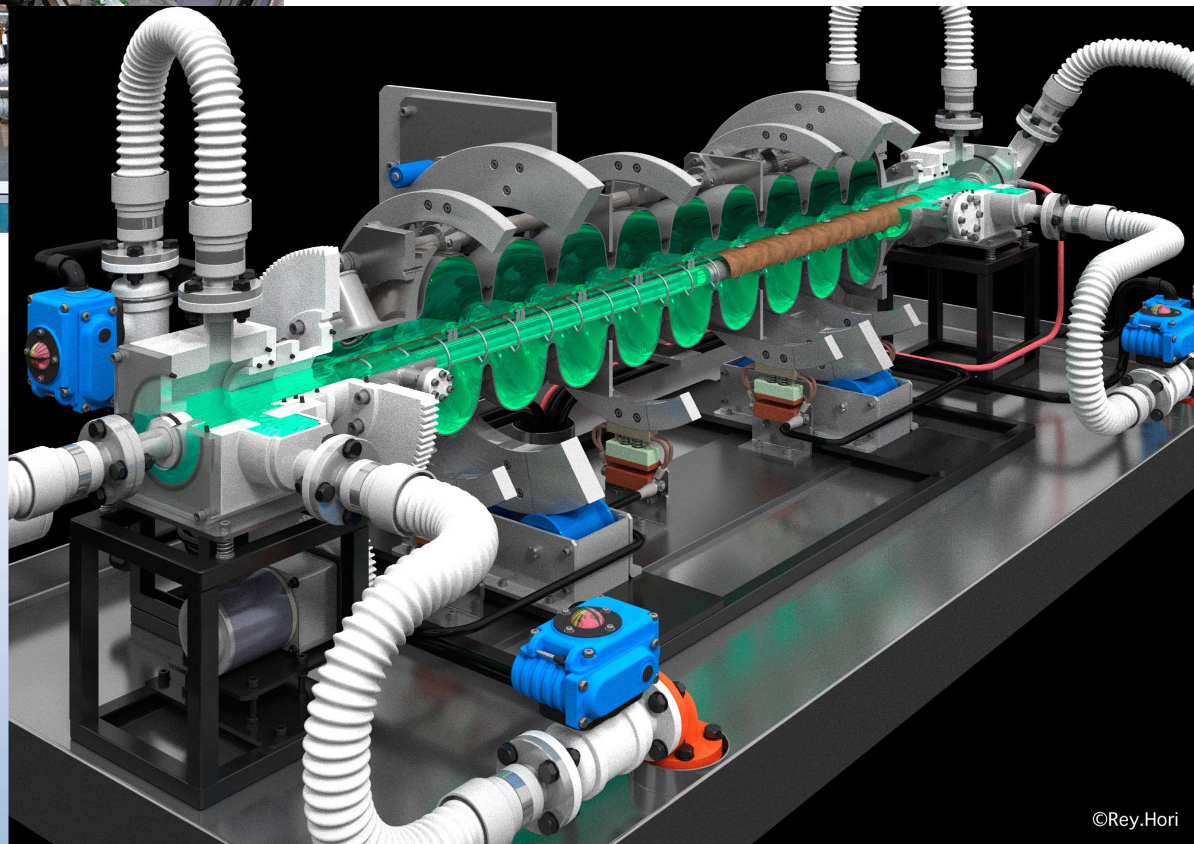
Cavity Surface Treatment



Electro-Chemical Polish

Use Sulfuric acid + HF mixture
Apply voltage
between center Al electrode and Nb cavity
Optimize parameter for smooth surface
without sulfur residual particle
voltage and temperature are key parameter
Successive rinsing is another key technology

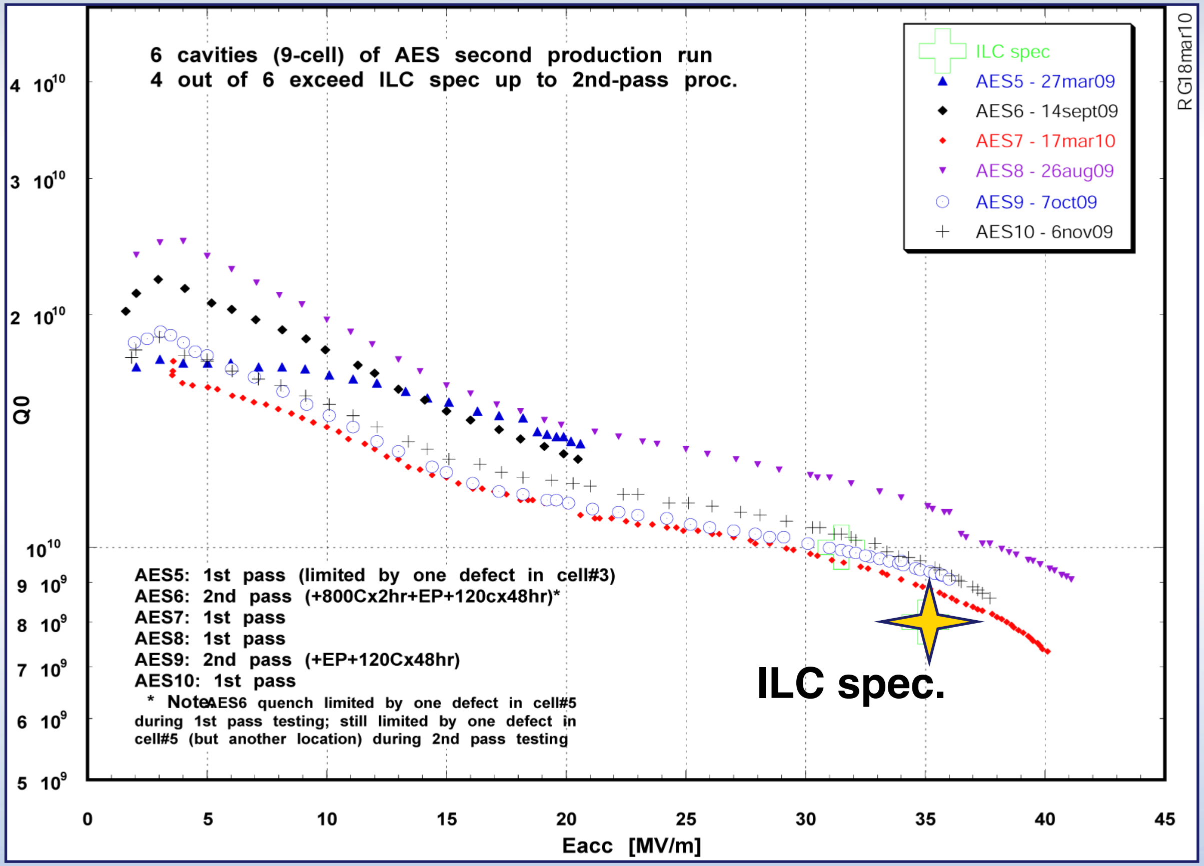
KEK STF EP as an example



Cavity Testing

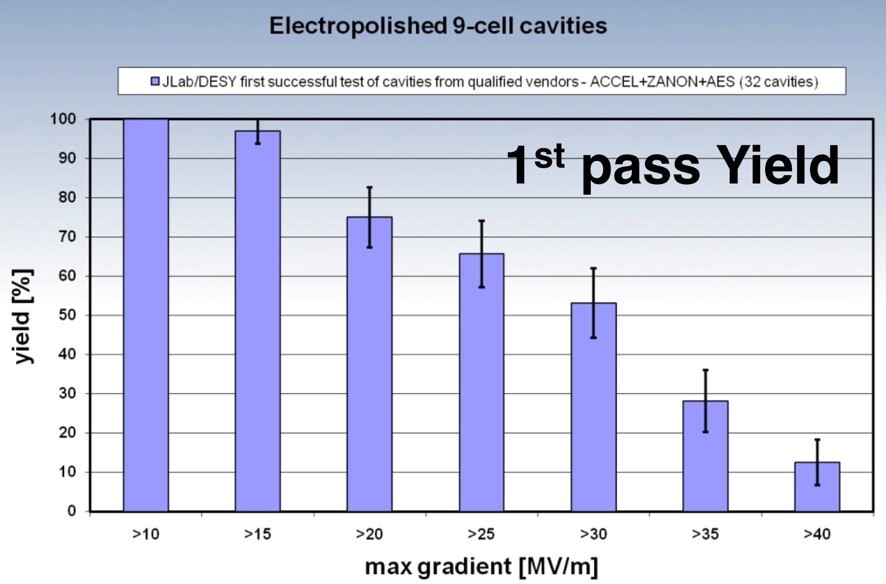
Vertical Dewar test for gradient performance check. (KEK-STF as an example)

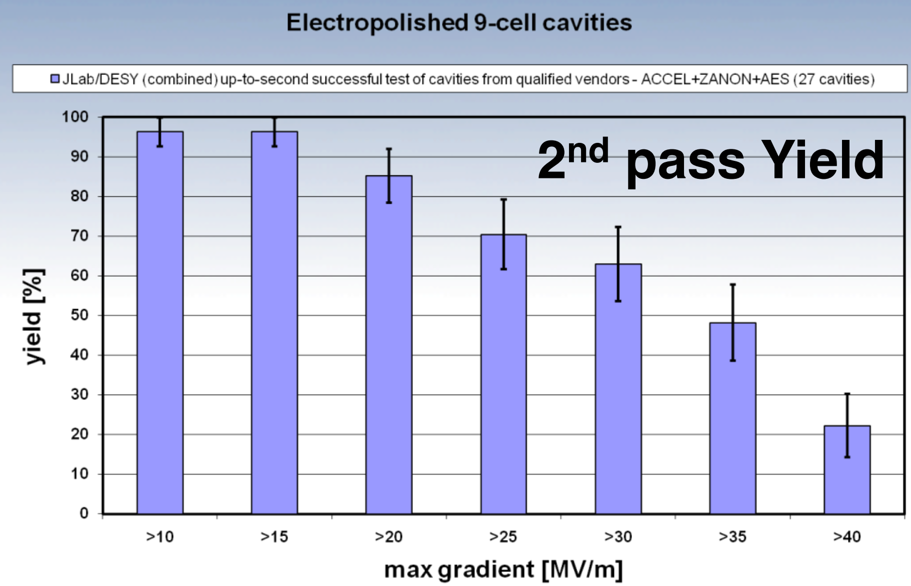
JLAB: AES cavity results March 09 – March 10

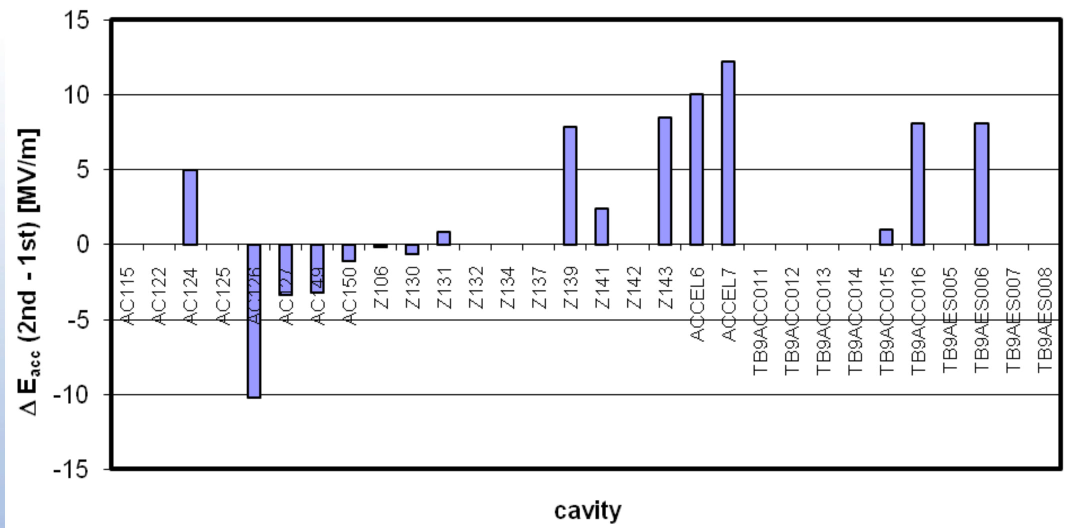


Successive 4 cavities are beyond 35MV/m

Gradient Performance of TESLA cavities





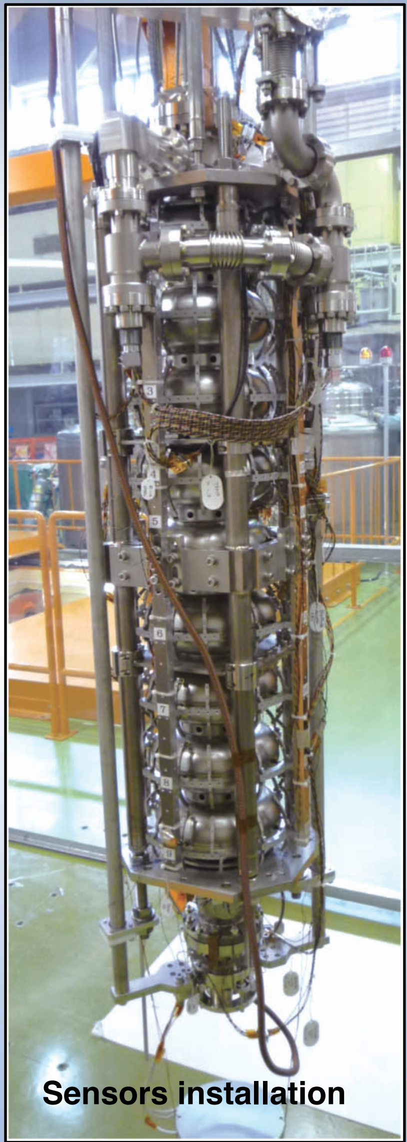


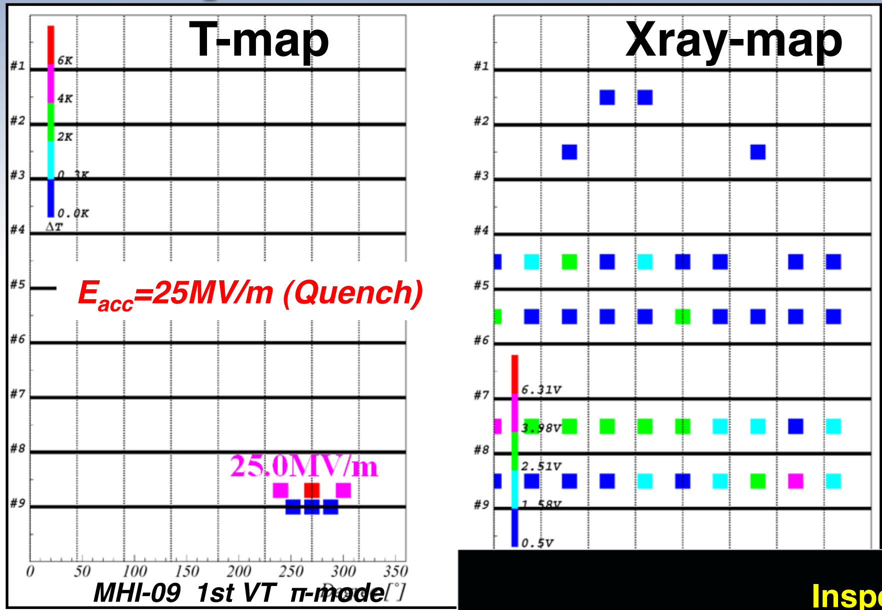
Qualified vender recent 32 cavities
(27 cavities for 2nd pass.) in the statics

>35MV/m : 48% Yield

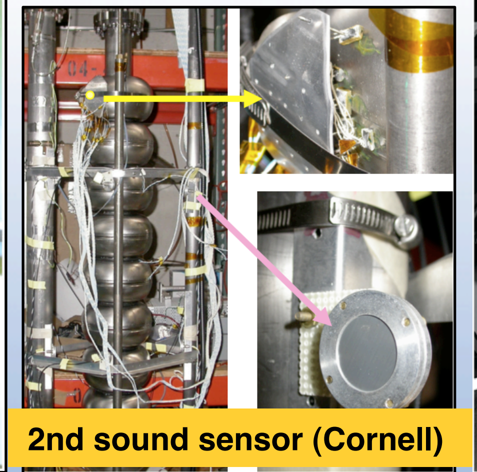
ILC-GDE
Cavity Database Team
Mar.28, 2010 Beijing meeting

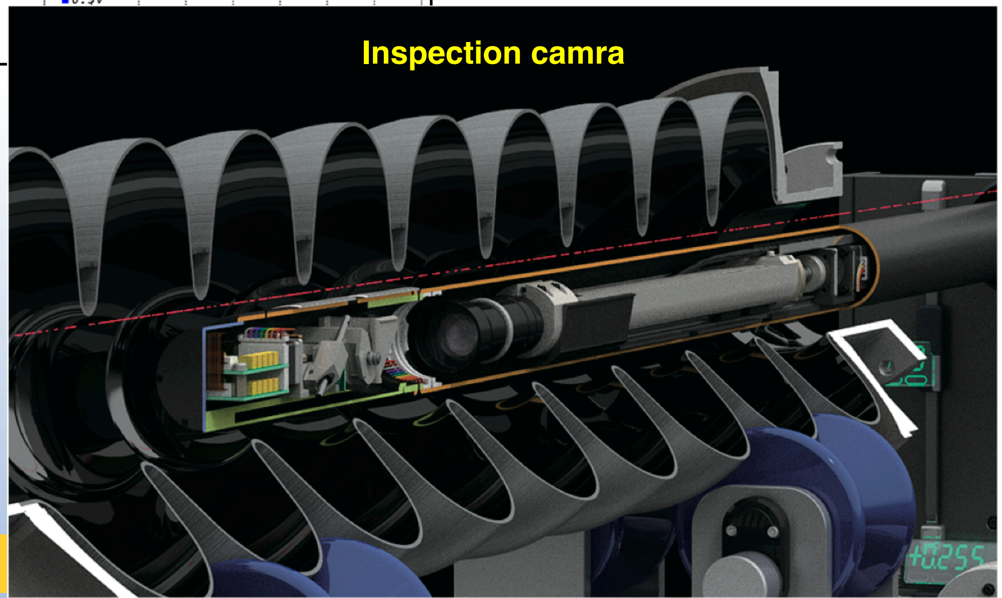
Diagnostics Instruments for quench location identification


Sensors installation



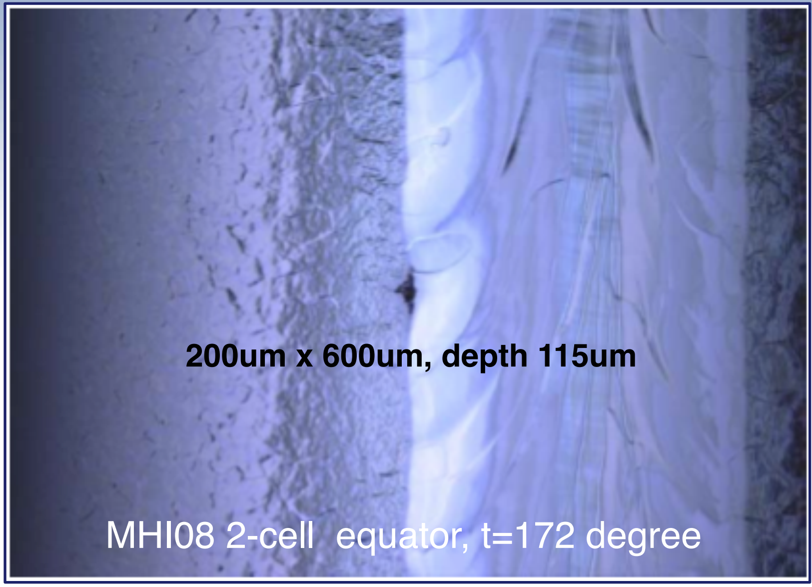
T-map & Xray-map, 2nd sound sensor together with pass-band mode measurement, location of quench is identified.
Inspection camera visualize what's happen inside.


2nd sound sensor (Cornell)


Inspection camra

What's inside at quench location

for example



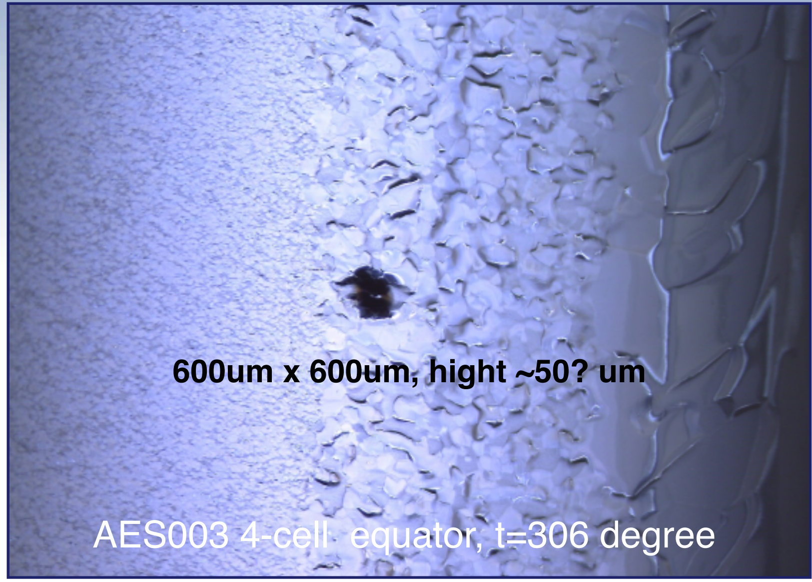
Pit; appeared after bulk EP, limit to 16MV/m

↓ local grinding & EP

27MV/m

↓ additional EP

38MV/m



Bump at heat affecting zone, limit to 20MV/m

↓ local grinding & EP

30MV/m

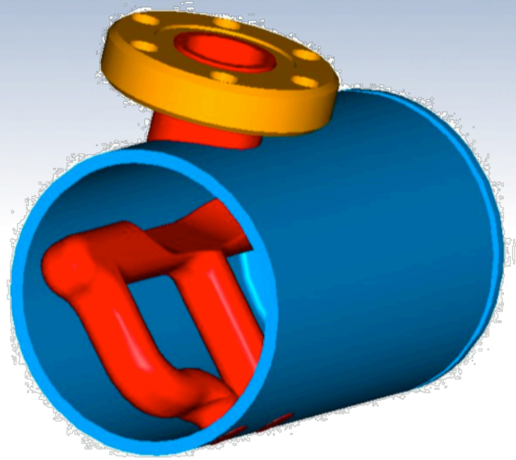
↓ additional HPR and bake

34MV/m

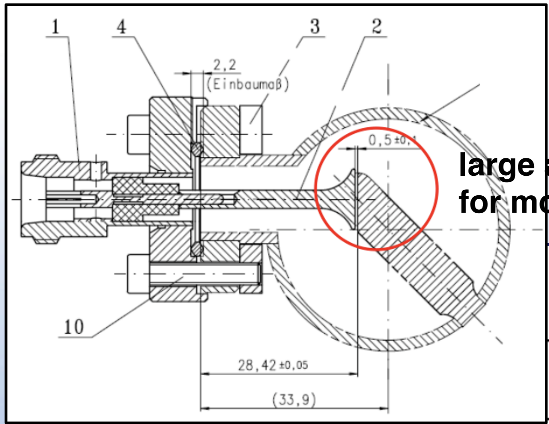
Technology for High Quality Beam

HOM Damper

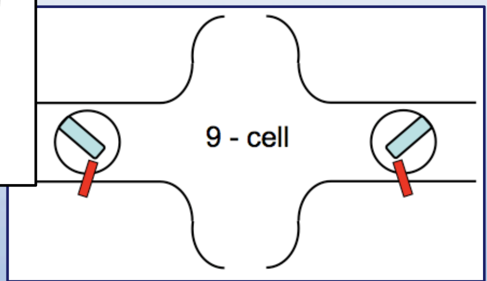
XFEL, project-X, ILC



TESLA Cavity HOM Coupler

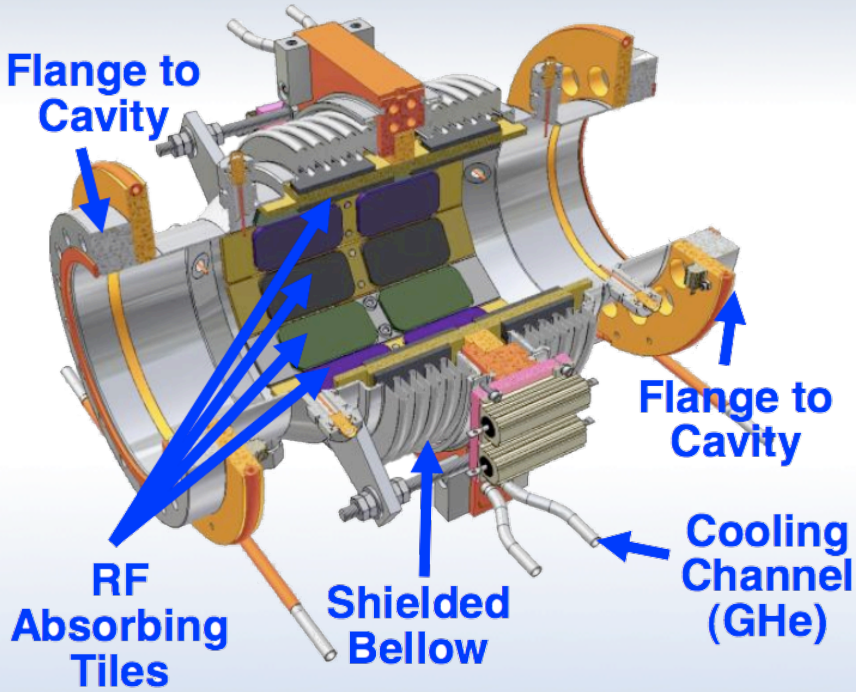


large area pickup
for more gap distance



mirror symmetry orientation,
asymmetric shape of half end-cell

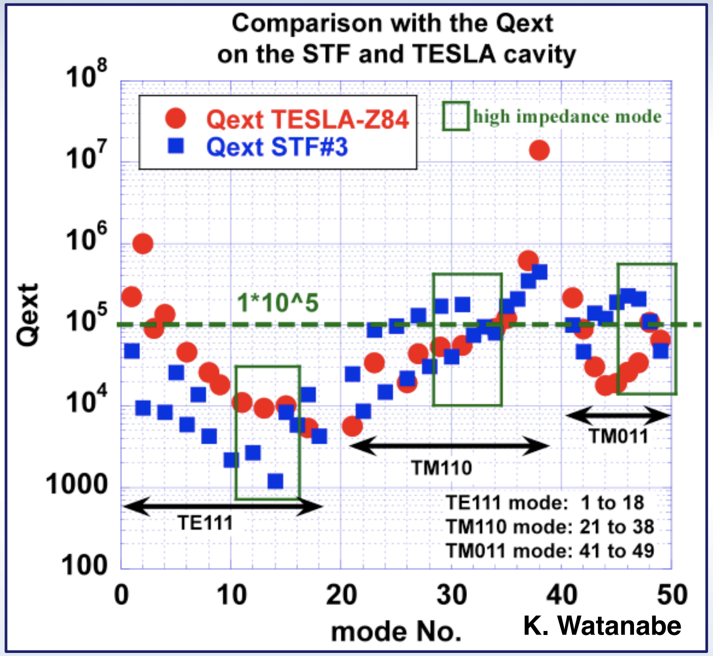
ERL applications



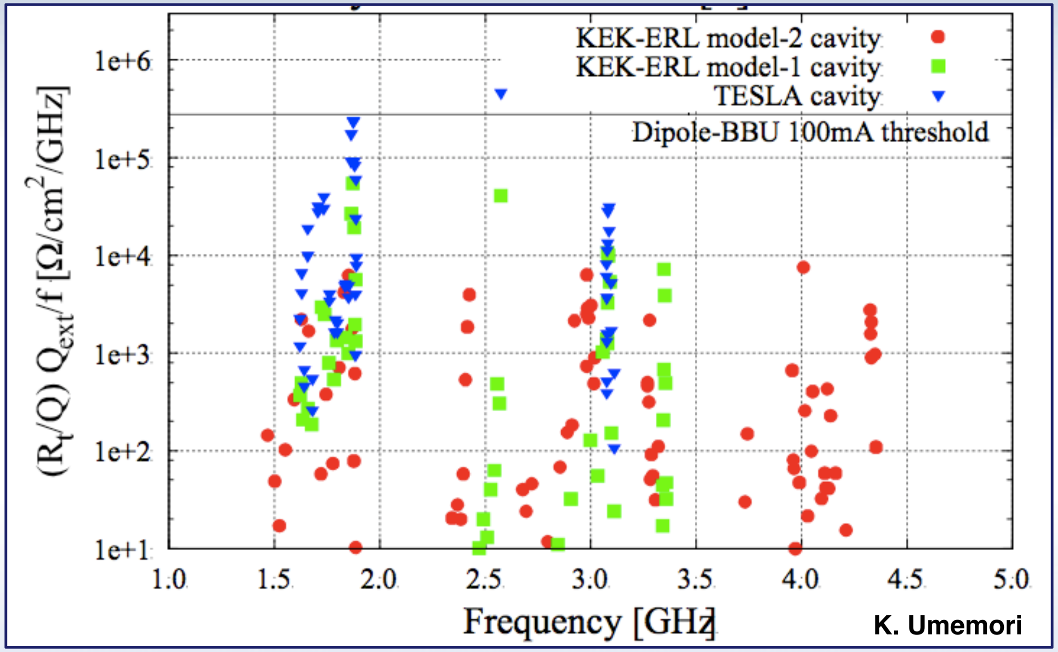
Cornell beam pipe HOM absorber
of ERL 2 cell injector cavity

HOM Damper Performance

TESLA cavity HOM Qext

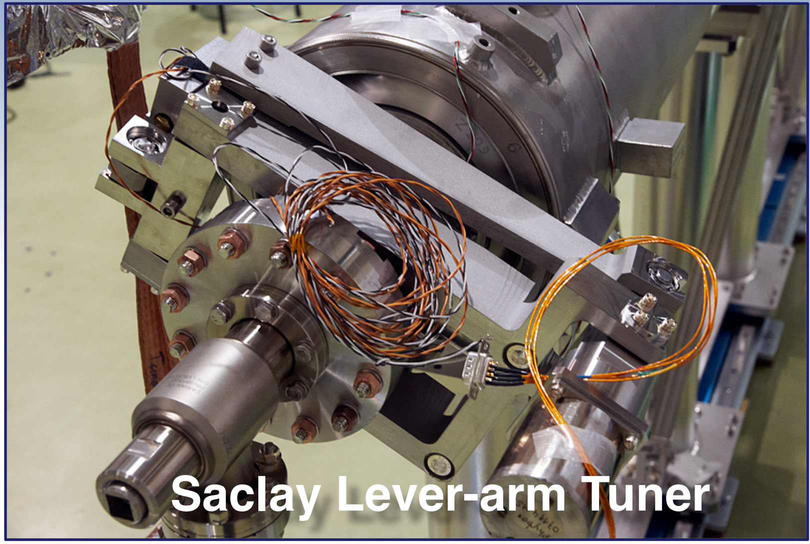


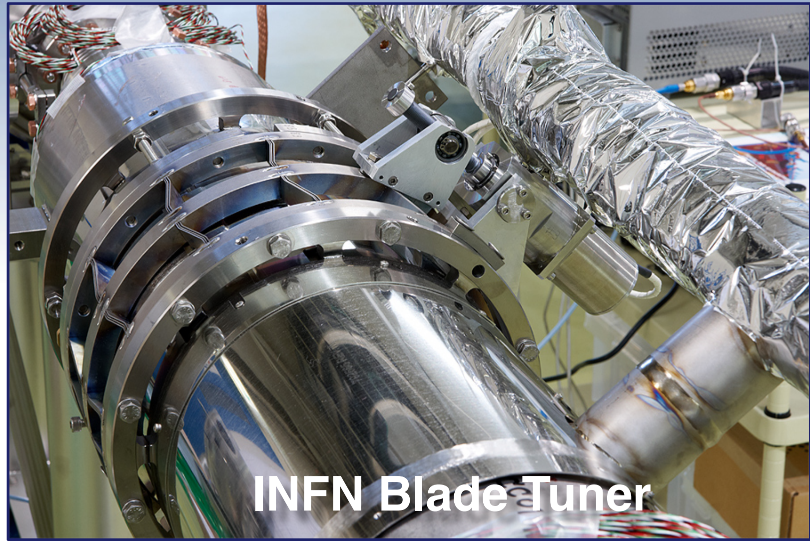
KEK 9cell ERL cavity HOM Impedance

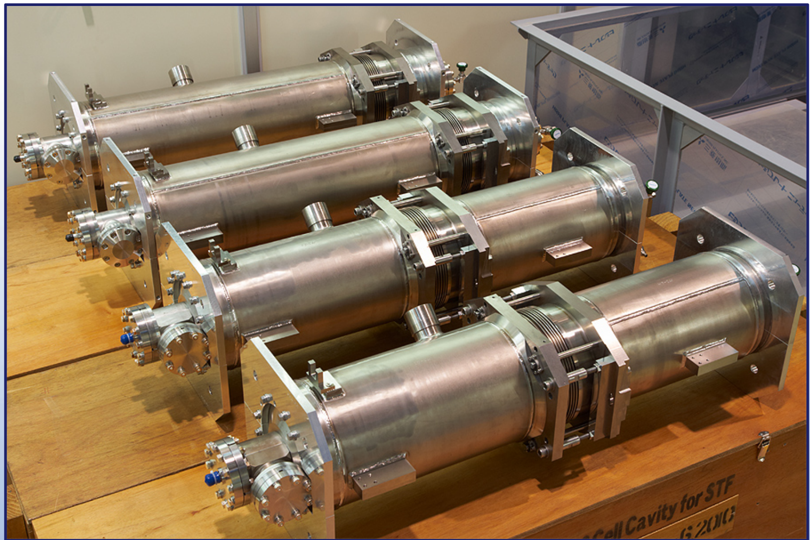


HOM impedance by Beam pipe HOM absorber damping is two-order smaller than TESLA HOM coupler damping.

Frequency Tuners for Pulsed RF operation





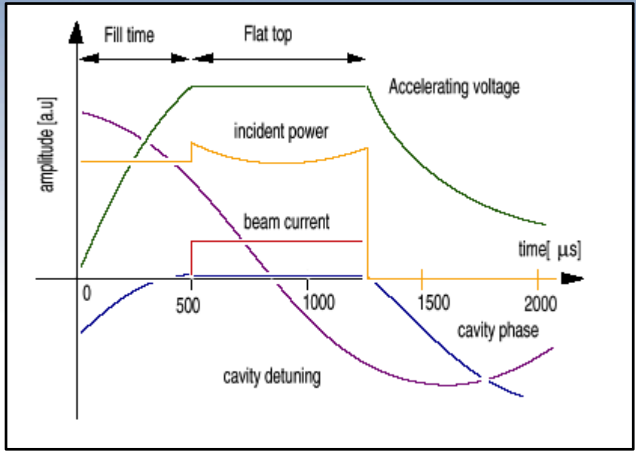


Piezo actuator installed mechanical tuner for frequency control

GDE S1-Global project is a test stand of these three kind tuner comparison.
(actually 4 kind of tuners)

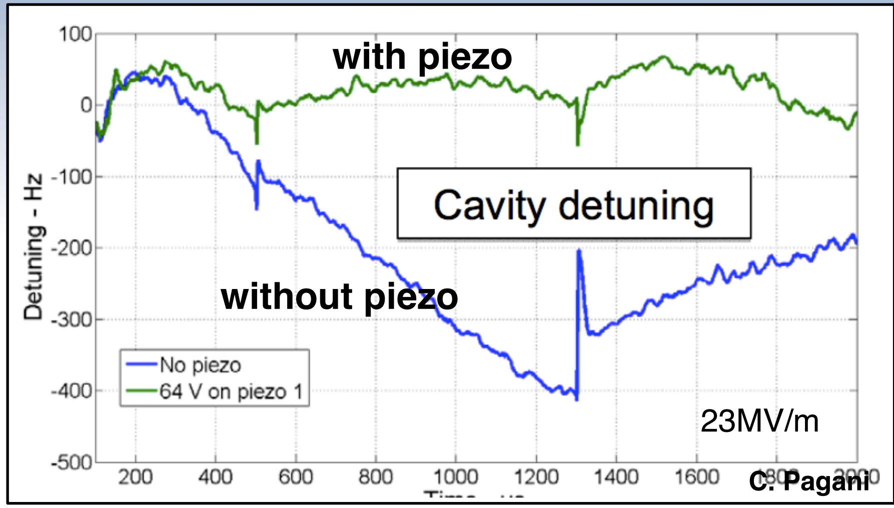
Slide-jack Tuner in the center, or in the end

Lorentz Force Detuning Compensation

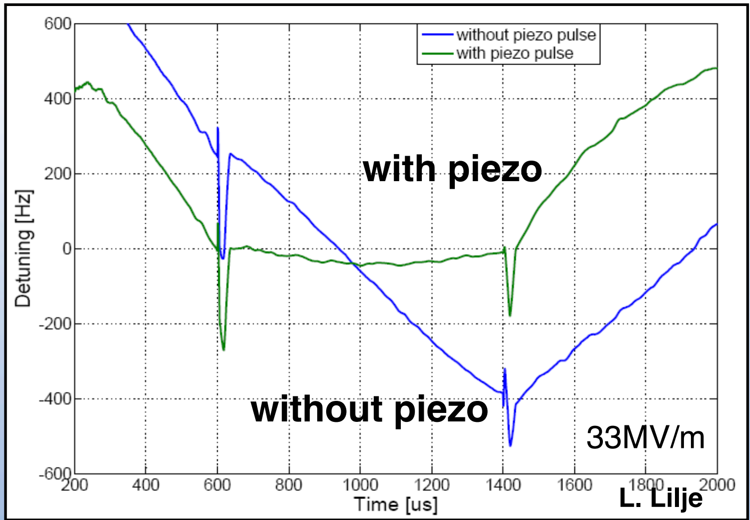


At pulse flat-top, detuning still continues, the phase is still shifted. To fit into digital feedback allowable range, piezo is activated by half-sine wave pulse.

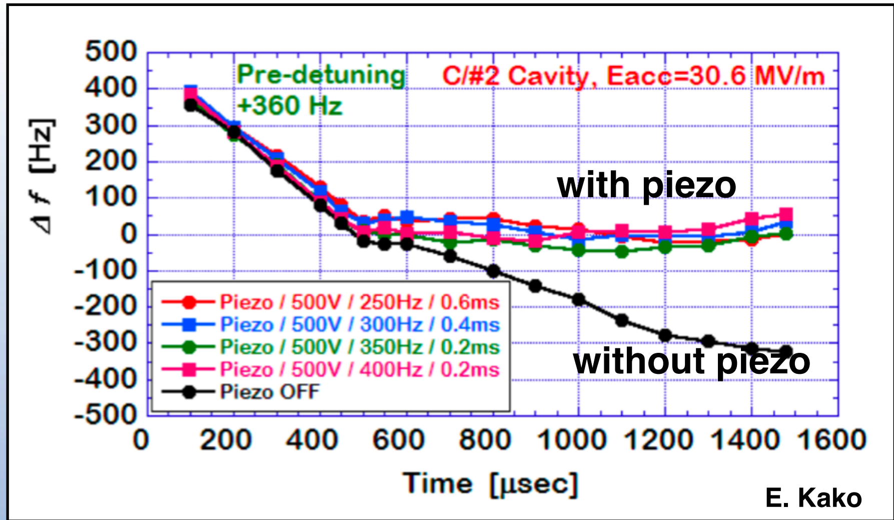
Blade Tuner



Lever-arm Tuner



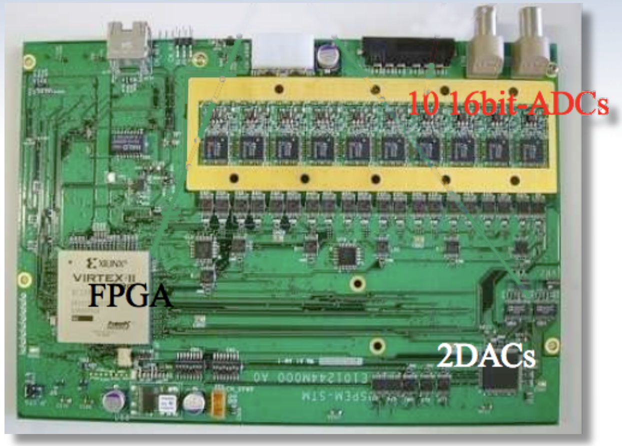
Slide-jack Tuner



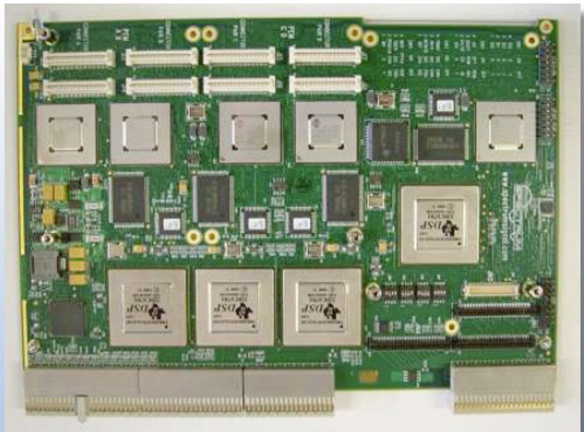
Precise digital feedback control with feed forward

cavity pickup -> Down converter -> AD -> FPGA -> DA -> IQ modulator

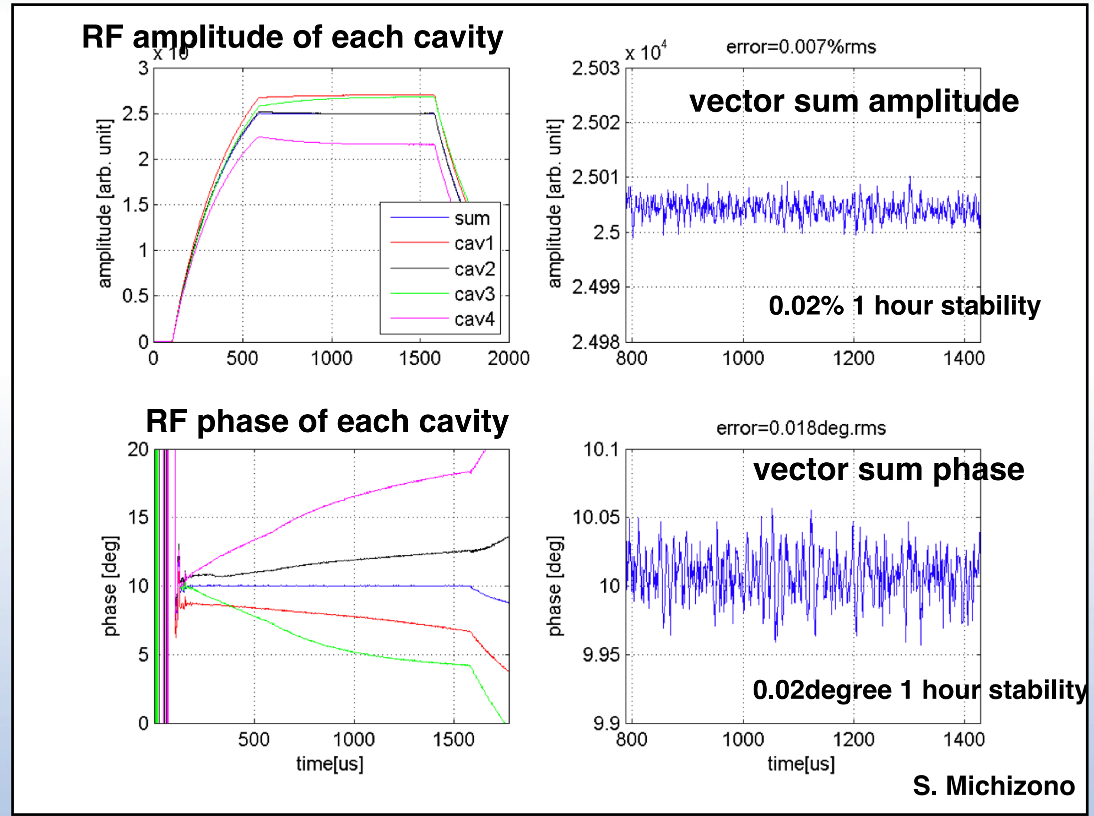
By vector sum control



STF FPGA Board



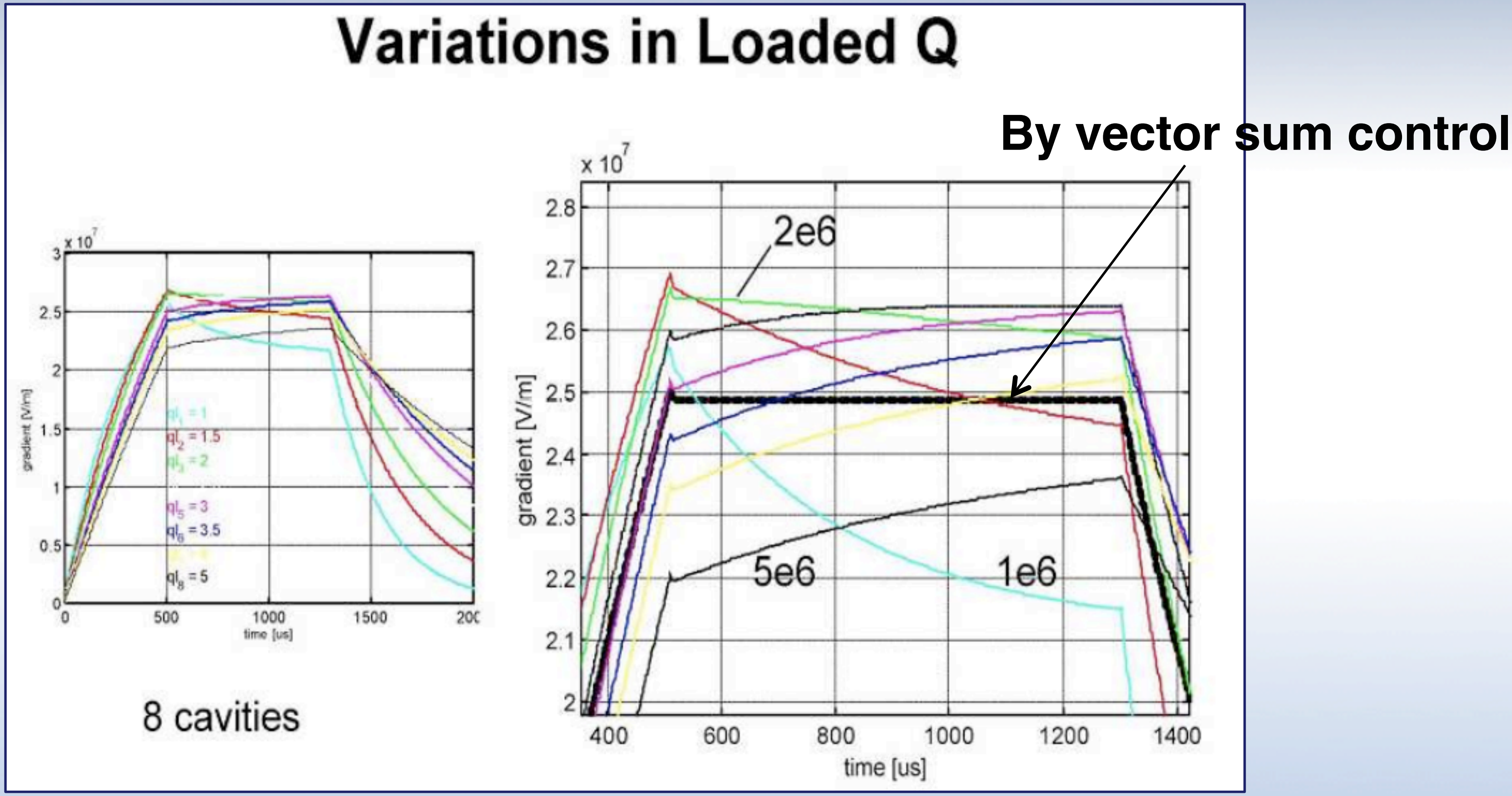
STF DSP Board for online diagnostics



STF feedback boards and its performance as an example

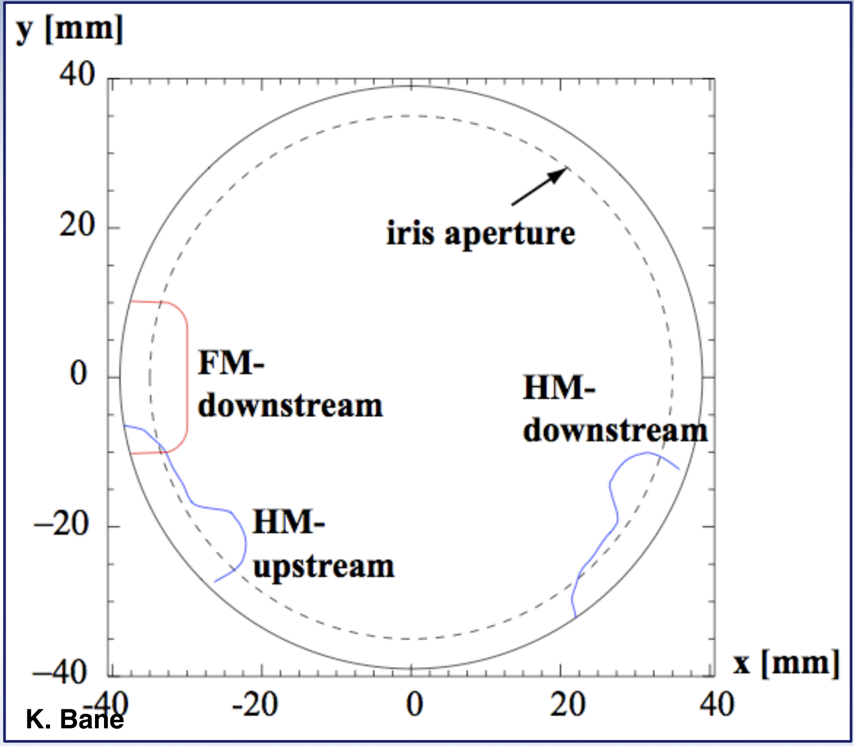
QL tuning in vector-sum feedback control

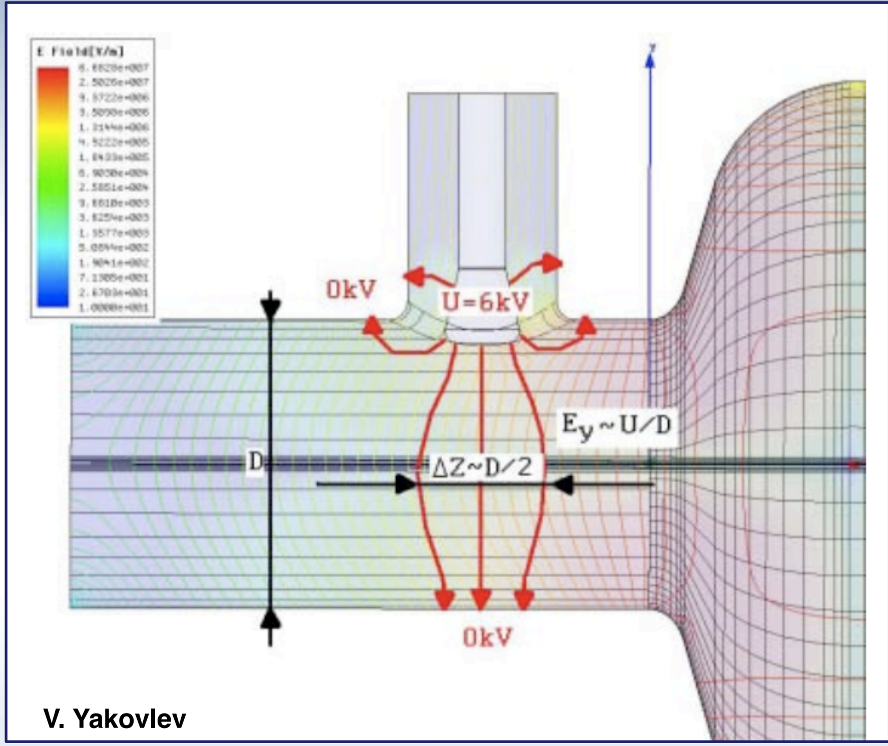
In case of multi-cavities cryomodule powered by single klystron



When QL of each cavity are variated, voltage at flat-top will variate, and weak cavity tend to reach its quench level.
Even if QL are adjusted for nominal beam loading by tuning of input coupler coupling etc, the voltage will variate in case of beam off.

Coupler kick issue

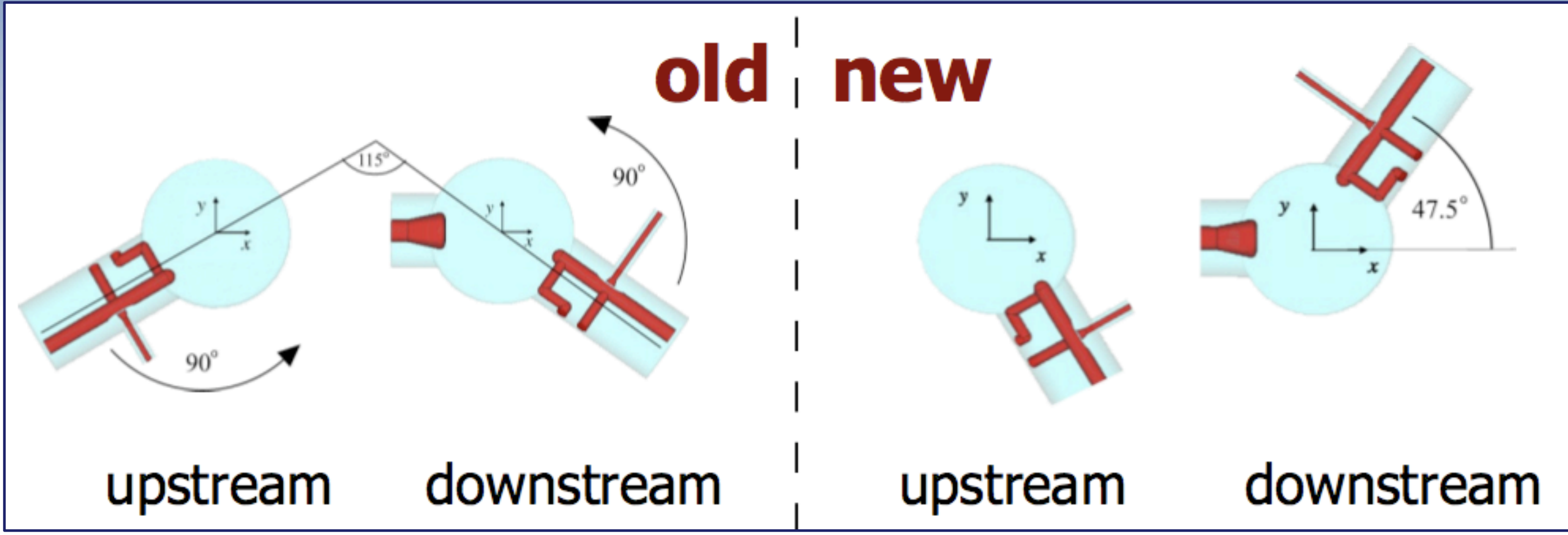




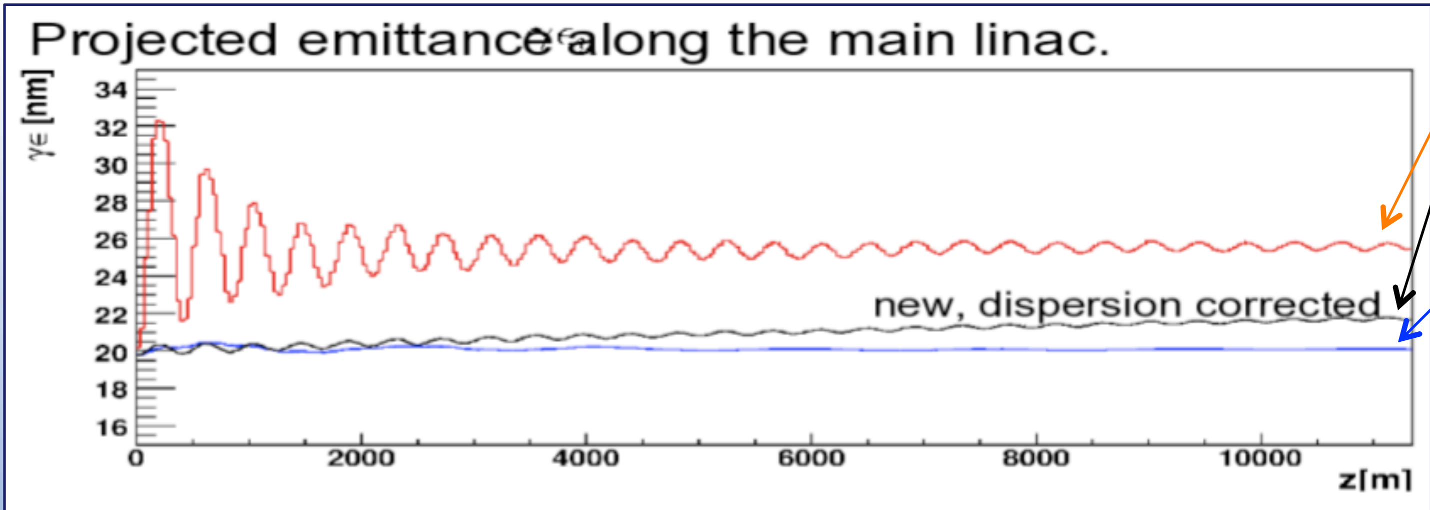
Asymmetric arranement of couplers introduced discussion on emittance growth in ILC main Linac, in 2006-2008.

RF field asymmetry by main coupler and HOM antenna is another issue for beam kick.

Coupler kick effect in ILC Linac



reduced wake-field in new design, but it increase RF kicks.
(Dirk Krucker, Chicago GDE-meeting, Nov.2008)



for 20.0nm
(input emittance)

new design
25.1nm
(no correction)
21.8nm
(dispersion corrected)

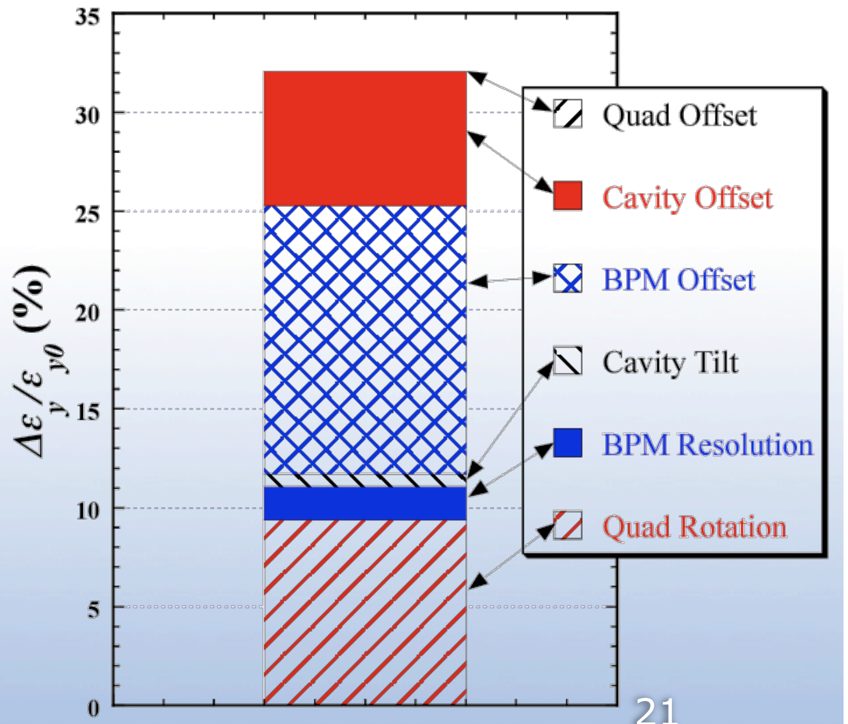
old design
20.3nm
(no correction)
20.3nm
(dispersion corrected)

Alignment Tolerance of ILC Linac

Assume following local misalignment only

	Vertical	Horizontal
Quad Offset (μm)	360	1080
Quad Roll (μrad)	300	
Cavity Offset (μm)	640	1920
Cavity Pitch and Yaw (μrad)	300 (pitch)	900 (yaw)
BPM Offset (μm)	360	1080
BPM Roll (μrad)	0	
BPM resolution (μm)	1	1
BPM scale error	0	0

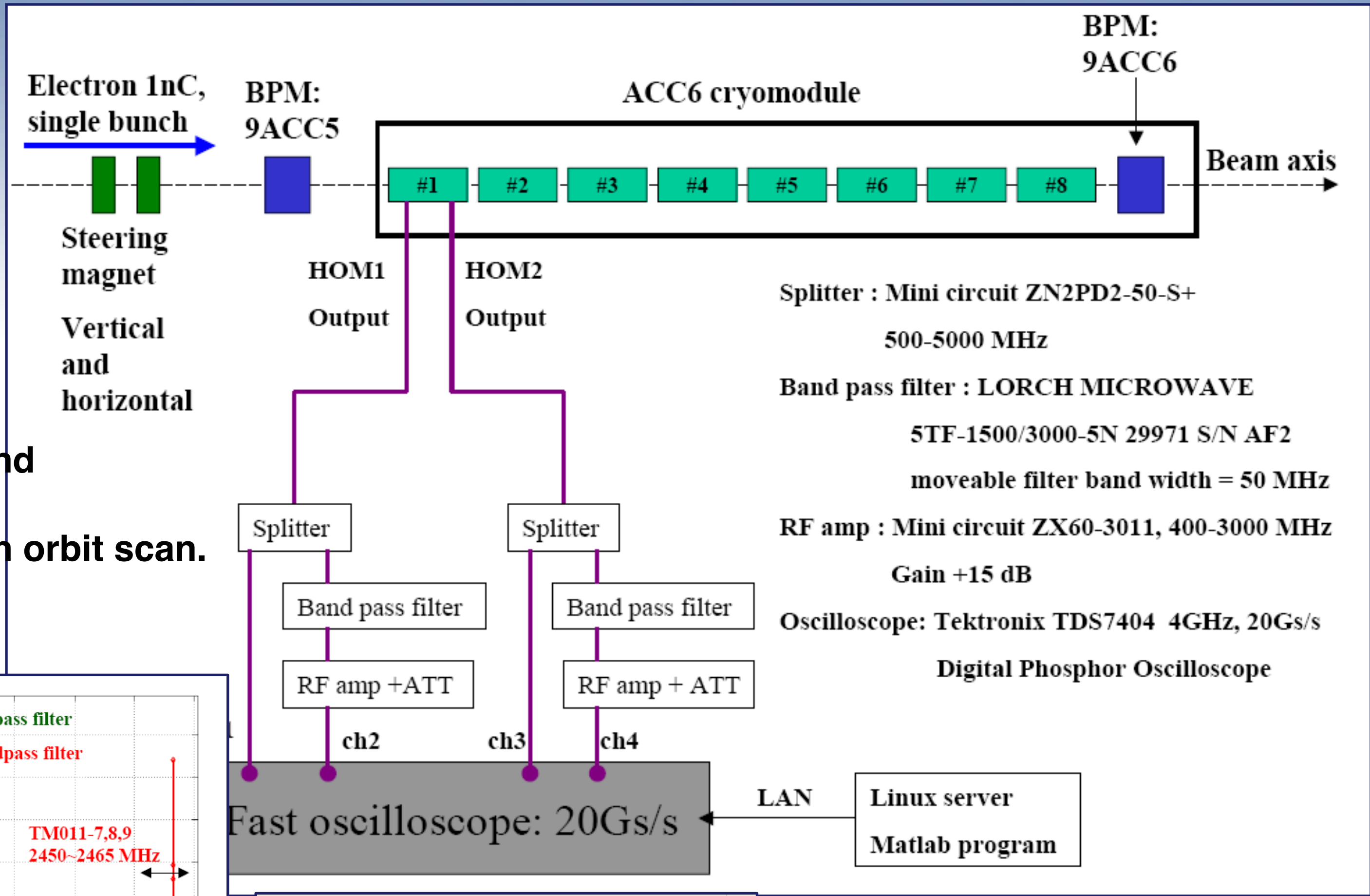
Cavity offset contribution to vertical emittance growth is 7%
Cavity tilt contribution is 1%



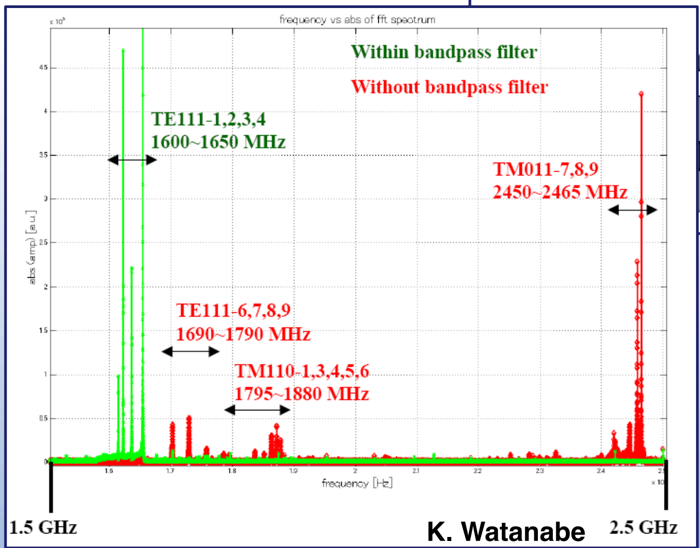
Simulation by code SLEPT,
using DMS(Dispersion Matching Steering),
15GeV -> 250GeV

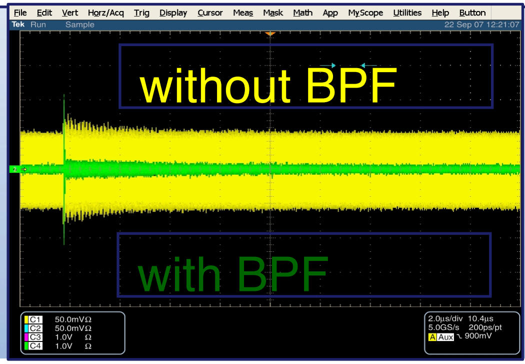
(K. Kubo, Beijing GDE-meeting, Mar.2010)

HOM-BPM for Alignment Confirmation



HOM pickup RF signal and BPMs are recorded for many beam passage with orbit scan.

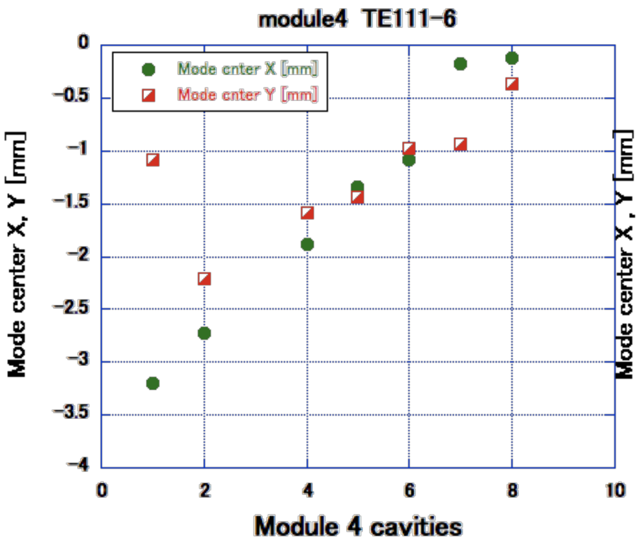




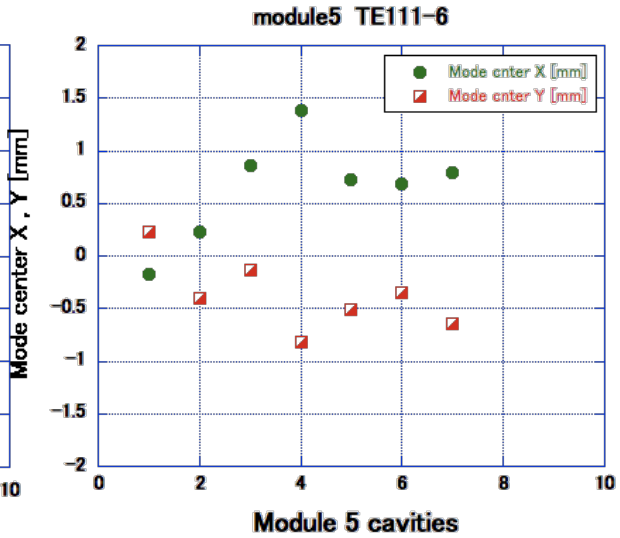
Cavity offset in cryomodule by HOM-BPM

FLASH module 4, 5, 6: cavity offset measurement

Recorded HOM signal are analyzed to estimate HOM center and polarization axis.
Cavity offsets are estimated by HOM center, relative to BPMs axis.



S. Pei, EPAC08



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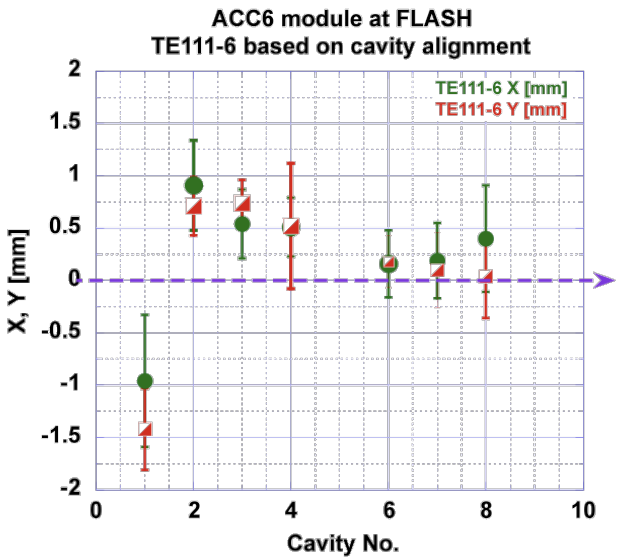


K. Watanabe

3 modules average offset: X= -0.21 +/- 1.23 mm
Y= -0.51 +/- 0.78 mm

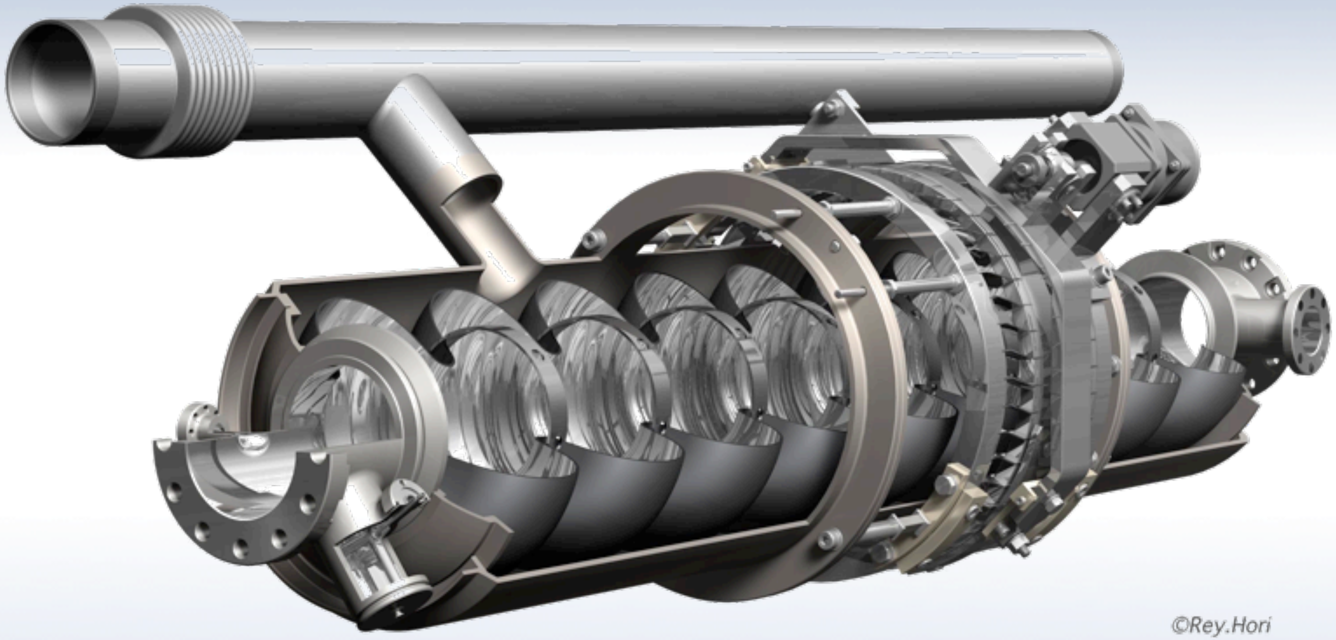
Summary

1. TESLA cavity is a major one among high performance cavities. Fabrication, treatment, tuning, and testing are reviewed. Its gradient performance is close to 35MV/m average.

2. Difference of XFEL,ILC application and ERL application are; HOM damper(antena or absorber),
   LFD compensation(Piezo compensation or not)

3. Following beam dynamics related issues are also reviewed;
   HOM damping,
   Piezo LFD compensation,
   Vector-sum digital feedback control for flat energy beam,
   Coupler kick issue,
   Alignment tolerance for long ILC linac,
   HOM-BPM method for alignment confirmation,
   Cavity alignment in the cryomodule need to be considered.

Thanks for attention.



The figures and pictures are borrowed from many collaborators and the following web-site: ILC-GDE, DESY, workshop presentations and conference papers.

I would like to appreciate to all of collaborators, paper authors and presenters.